

Superconductor Electronics
for
Deep Space Systems
and
High Performance Computing

Arnold H. Silver
TRW Space & Electronics Group
Redondo Beach, CA

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Benefits of Superconductor Electronics

- Very efficient thin film LSI technology
 - Operates at 100 GHz with 20 nW per gate dissipation
 - Lowest power-delay product at highest frequencies: 1 eV
 - Closest interconnect pitch, shortest inter-gate delay at high speed
 - Lowest dispersion interconnects
 - Highest BW interchip interconnect/MCM
 - 3-d circuitry and interconnect
- High reliability LSI
 - Radiation hard
 - No electromigration failure
 - No thermally activated failure
- Low RF loss
 - High Q resonators, filters, channelizers
- Low Noise, high sensitivity sensors
 - Coherent and incoherent detectors
 - MMW through FIR

Applications of Superconductor Electronics

High Performance at Ultra-low Power

- Analog-to-digital converter
- Digital receiver
- Digital-to-analog converter, programmable voltage standard
- Direct digital frequency synthesizer, waveform generator
- Low phase noise oscillator
- Wideband controllable true time-delay phase shifter
- High Q resonator, filter, channelizer
- Wideband low noise amplifier, receiver
- Multi-Gb/s packet switch
 - Communications
 - Computing
- Digital signal processor
- Digital computer
- (?) Quantum computer (?)

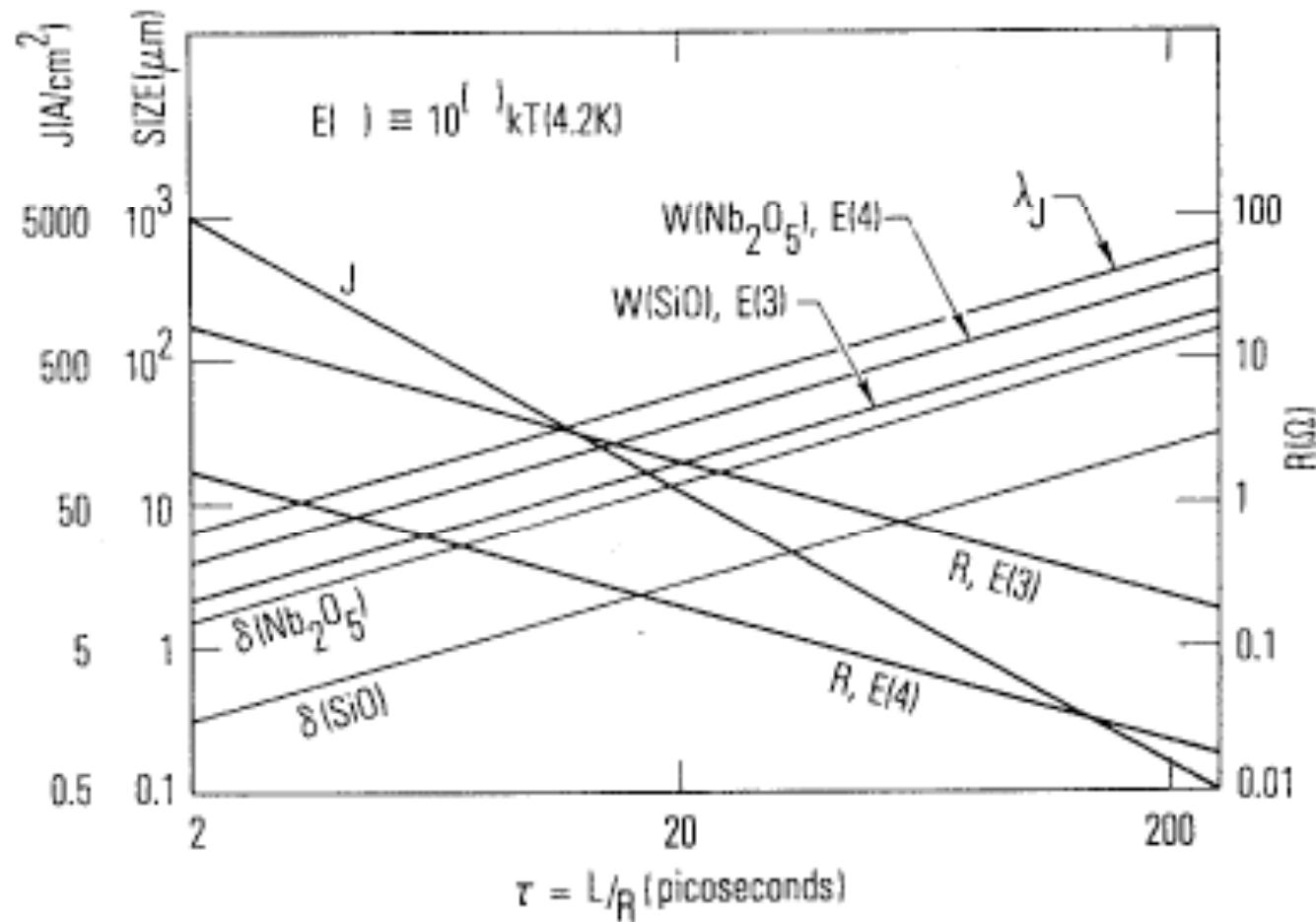
Superconductor Circuit Maturity

Technology	Integrated Circuit Status			Cryocooler Status		
	Today	3 - 5 years	Maturity	Today	3-5 years	Maturity
HTS Digital YBa ₂ Cu ₃ O ₇ @ 40-65 K	<ul style="list-style-type: none"> • 1-2 gates 	100-1,000 gates	Low	<ul style="list-style-type: none"> • TRW flight units • 30 W/W 	<ul style="list-style-type: none"> • Flown in space 	High
HTS RF/Microwave YBa ₂ Cu ₃ O ₇ @ 50-75 K	<ul style="list-style-type: none"> • Thin-film filters • Delay lines • Resonators • <u>Hybrid MMIC</u> 	Monolithic passive/ active thin-film HTS subsystems	Moderate	<ul style="list-style-type: none"> • TRW flight unit • 30 W/W 	<ul style="list-style-type: none"> • Flown in space 	High
LTS Digital NbN @ 10 K	<ul style="list-style-type: none"> • 500 - 1,000 gates 	10,000 gates	Moderate	<ul style="list-style-type: none"> • Experimental flight models • Development needed 	<ul style="list-style-type: none"> • Flight Unit • 1000 W/W 	Low
LTS Digital Nb @ 4-5 K	<ul style="list-style-type: none"> • 1,000 - 10,000 gates 	100,000 gates	Highest	<ul style="list-style-type: none"> • Commercial for ground systems • 2000 W/W 	<ul style="list-style-type: none"> • <1000 W/W 	Highest

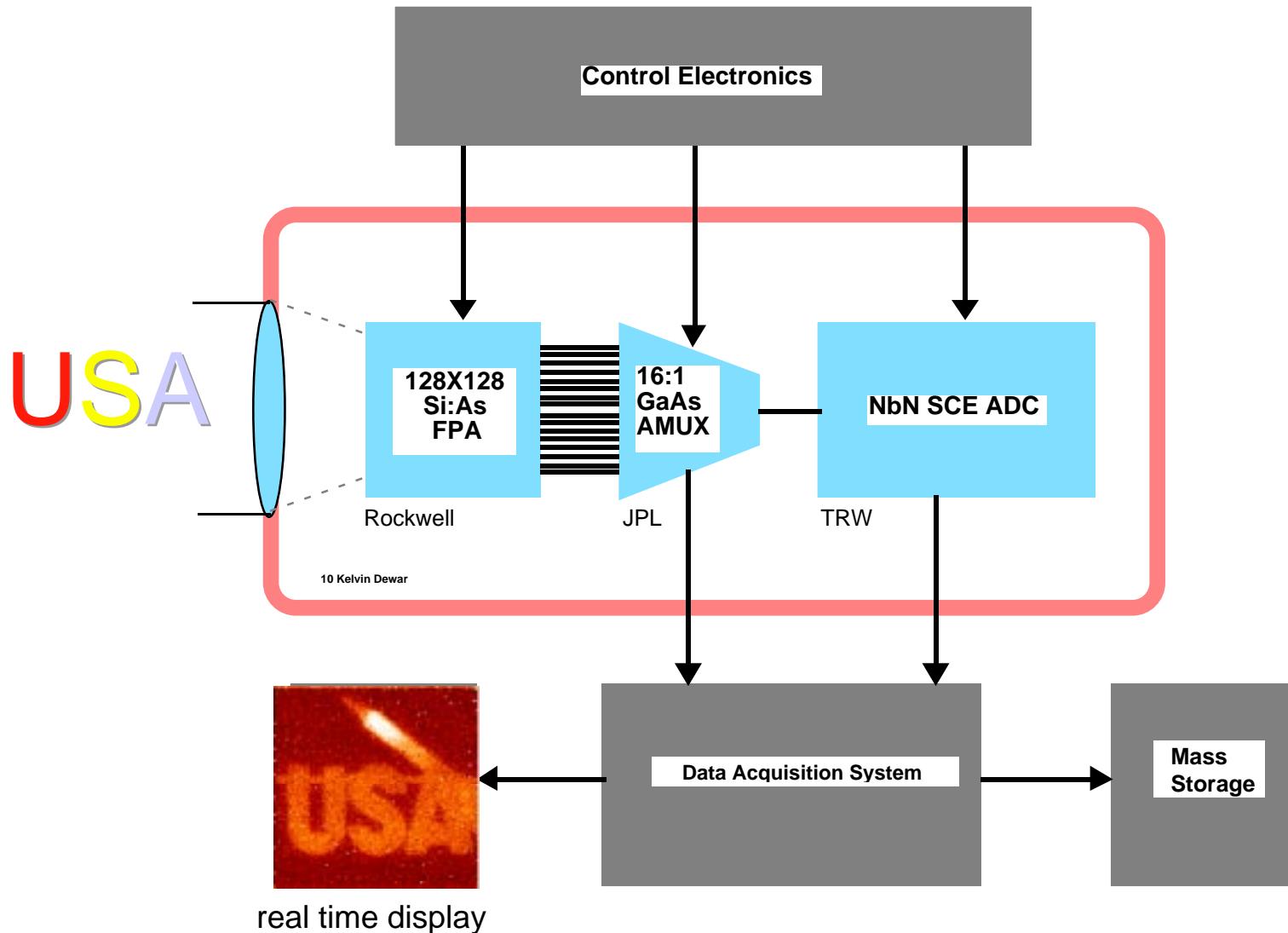
System-Level Demonstrations

- LWIR Sensor integrated with 10 K ADC
 - LWIR sensor integrated with 10 K ADC/digital time-dependent processor
- Direct digital frequency synthesizer 4 K
- 65 K digital MUX flight experiment
- 2.5 Gb/s crossbar switch
- 10 Gb/s packet crossbar switch

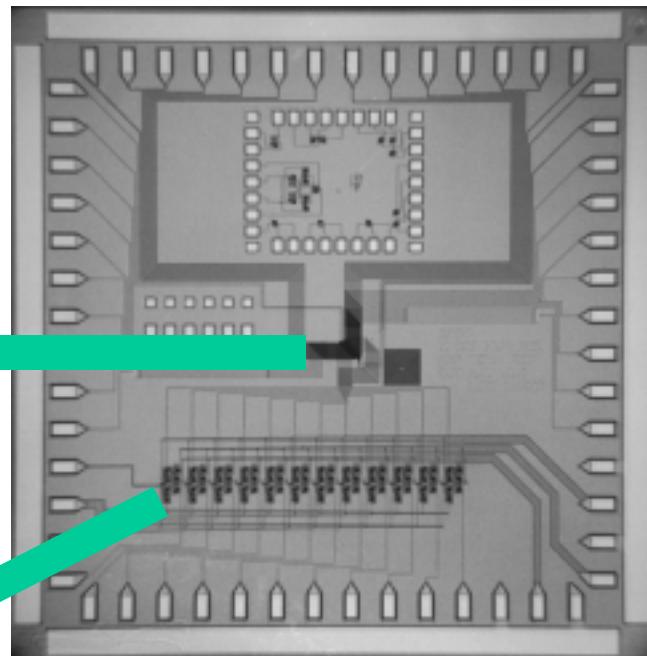
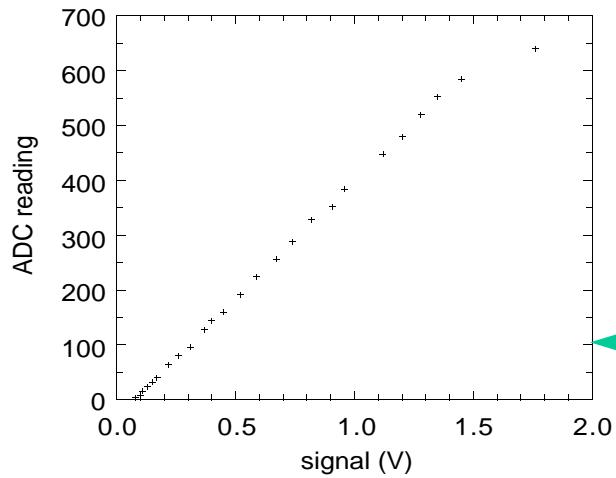
High Performance Digital Technology



IR Imaging System Uses a Single ADC

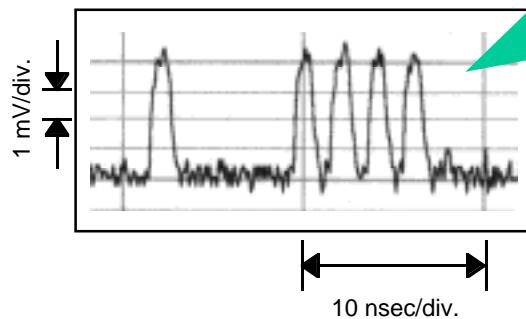


Successful ADC Operation



12-bit Parallel to Serial Output

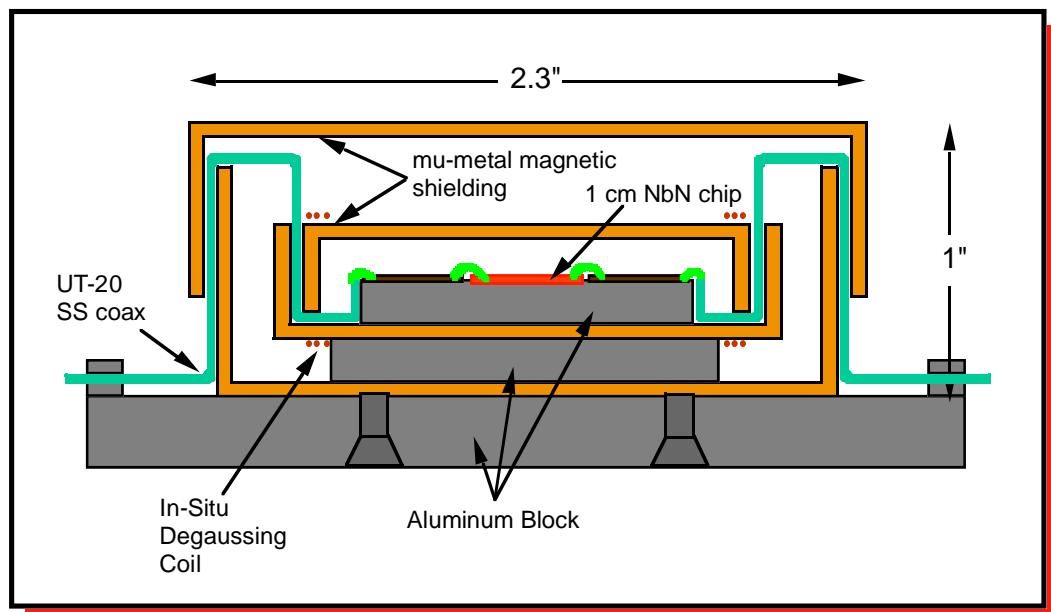
- 500 Mb/s
- 10 K operation



1-cm 12-bit ADC chip

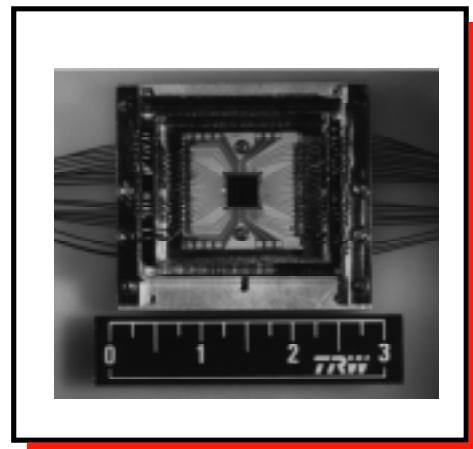
- SFQ counting ADC
- 2.5. MSps
- >10K operation
- 300 μ W

NbN ADC Package For Insertion In Sensor

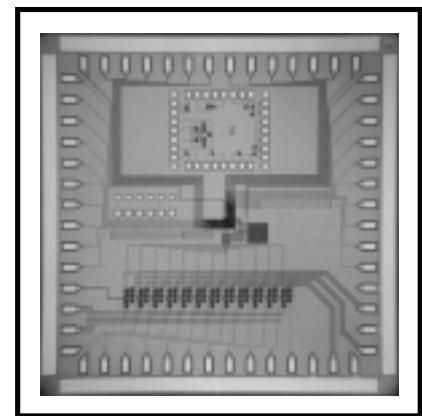


Cross-Section

Packaged Chip Prior To Delivery

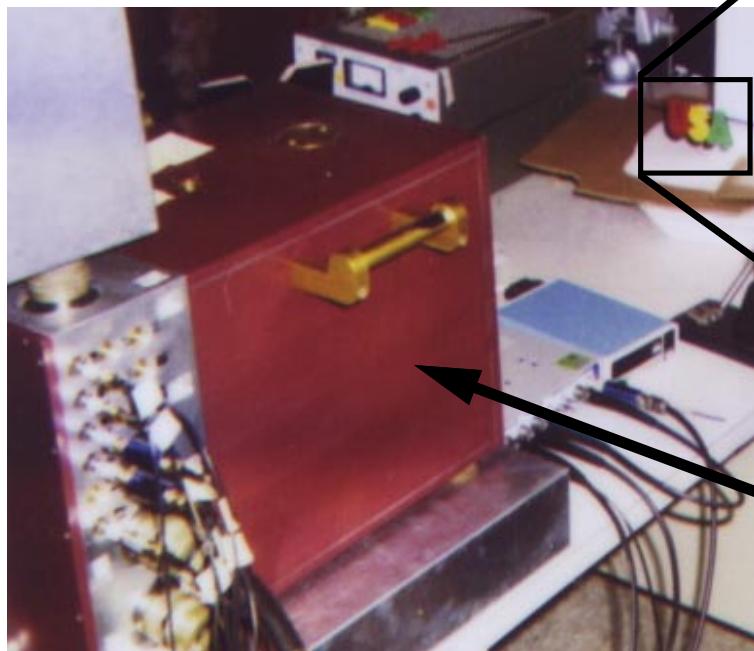


1-cm NbN ADC Chip

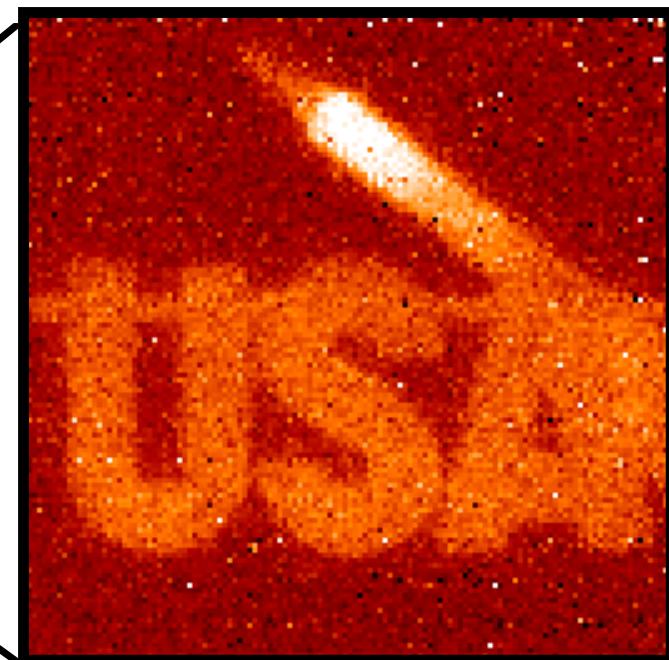


100 Frames/sec Images Using a Single NbN ADC

- 2 MSps conversion rate (100 frames/sec)
- 9 Kelvin
- 128 X 128 array
- ADC power = 300 μ Watt
- Frames captured in real time



IR Image of Room Temperature Letters with Cold Background

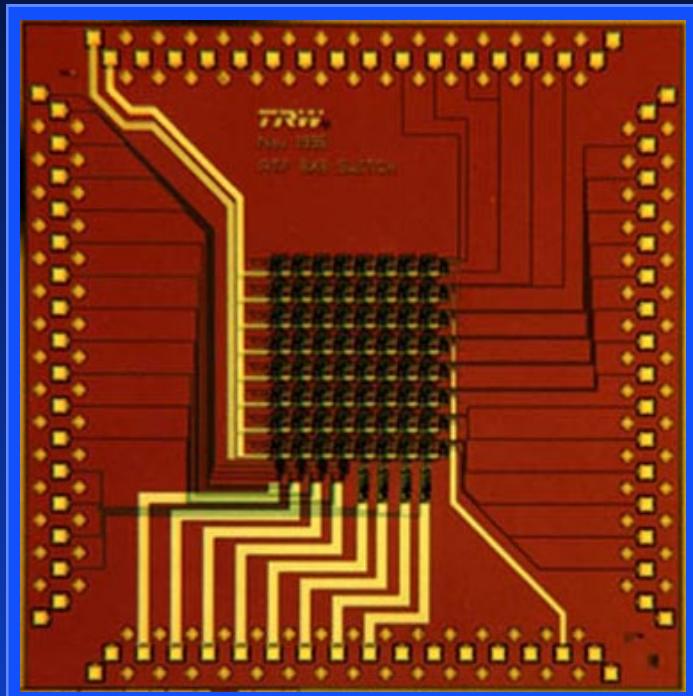


(three images averaged to reduce noise)

Dewar Containing IR Focal Plane Array,
Analog MUX, and NbN ADC

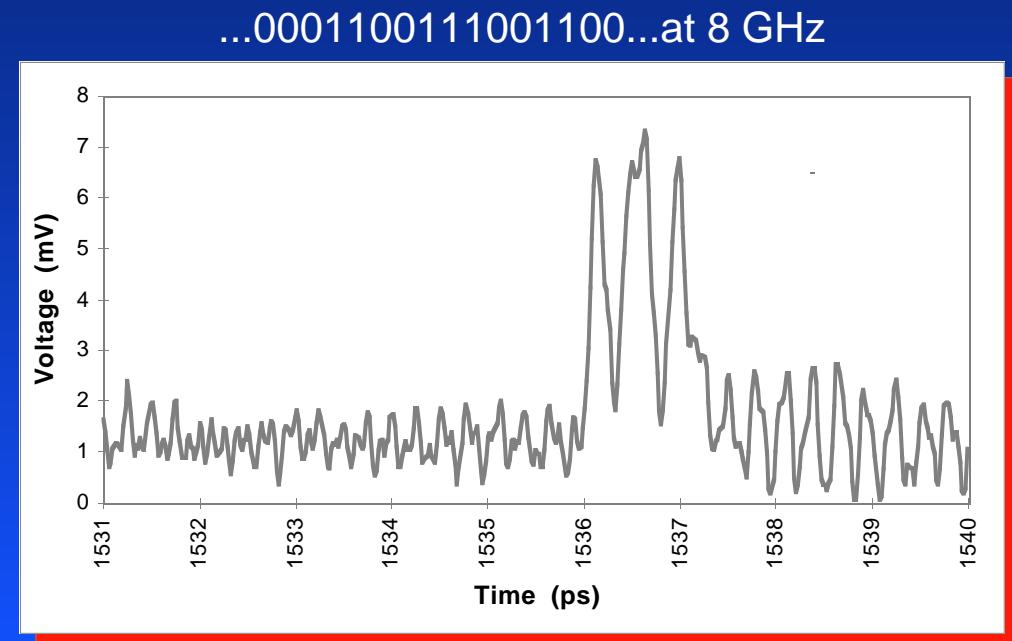
8 GHz Data Transmission Through Switch

TRW



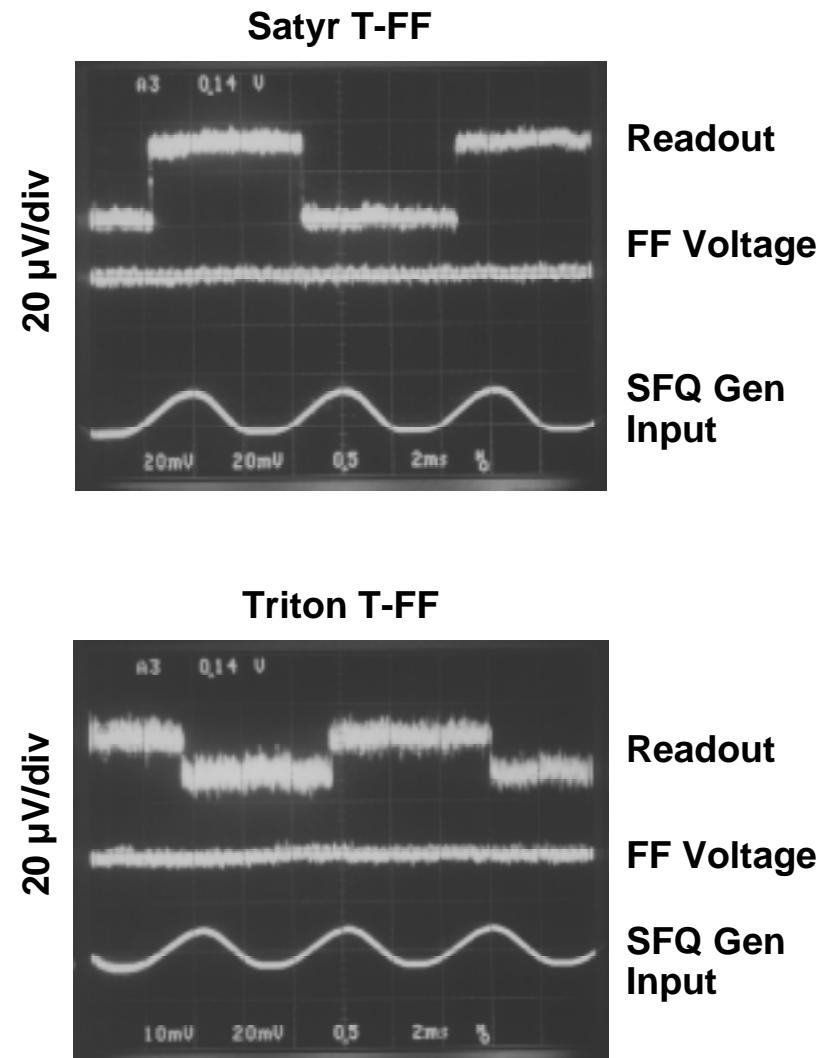
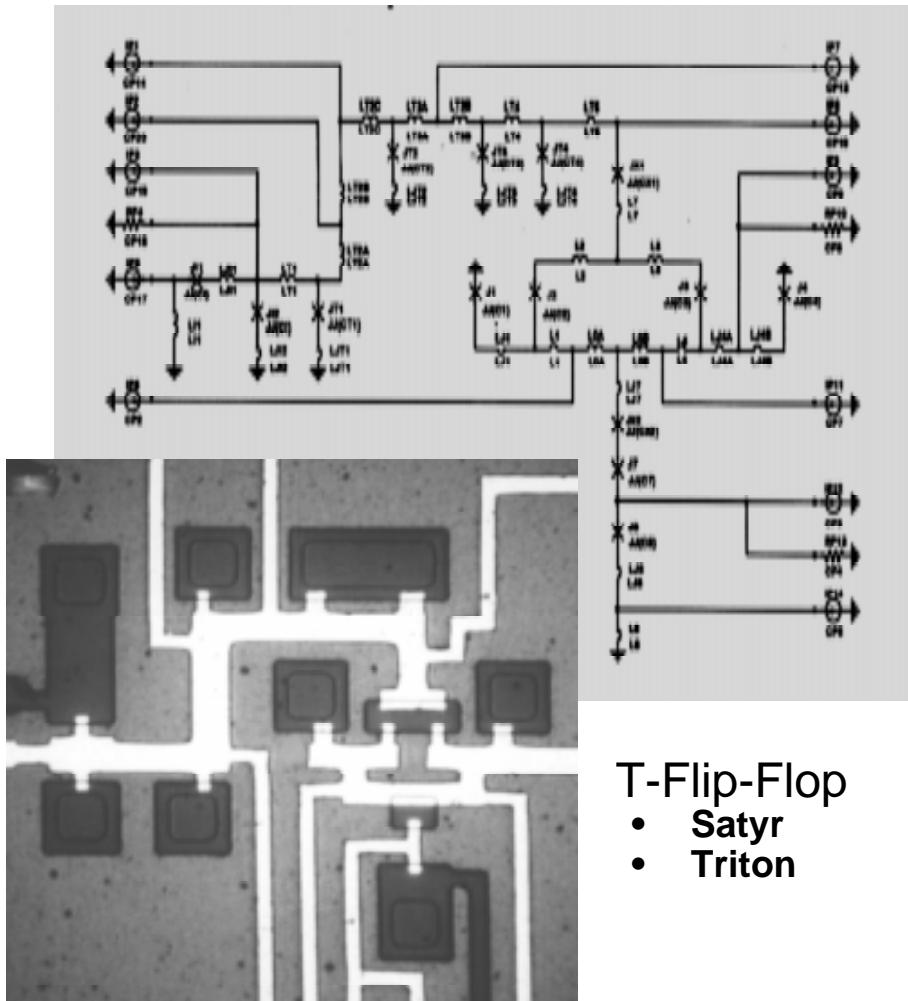
0.5 cm 8x8 SFQ Switch
with no on-chip amplification

- Switch fabric appears to be capable of data rates approaching 10 Gb/s
- Amplifier is critical component



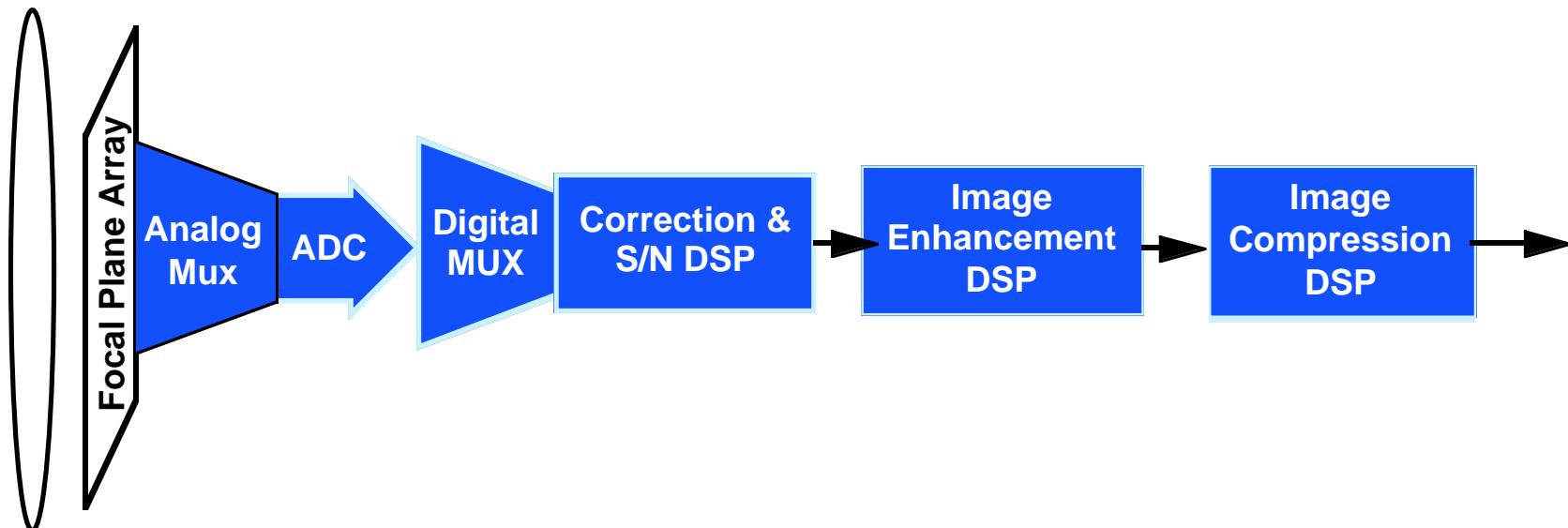
HTS SFQ T-Flip -Flops Operate at 65 K

TRW



Space Super Imagers

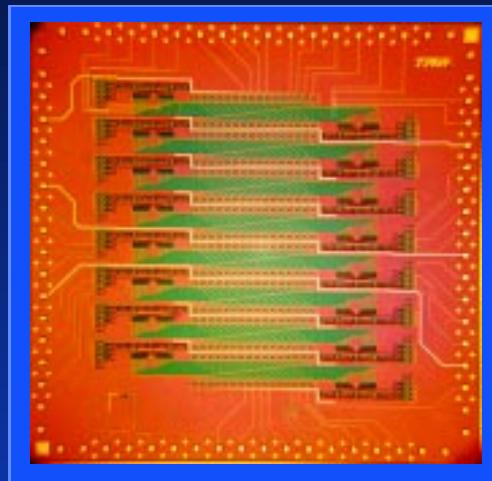
TRW



- Large cryogenic focal plane detector imaging arrays
 - IR: semiconductor detectors
 - FIR: superconductor detectors
 - MMW: superconductor detectors
- Integrated superconductor analog-to-digital converters
- Superconductor digital signal and image processors
- Superconductor digital data compressors

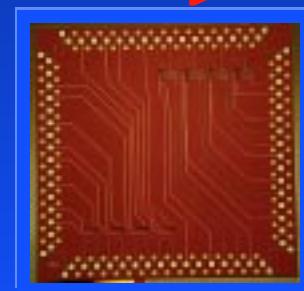
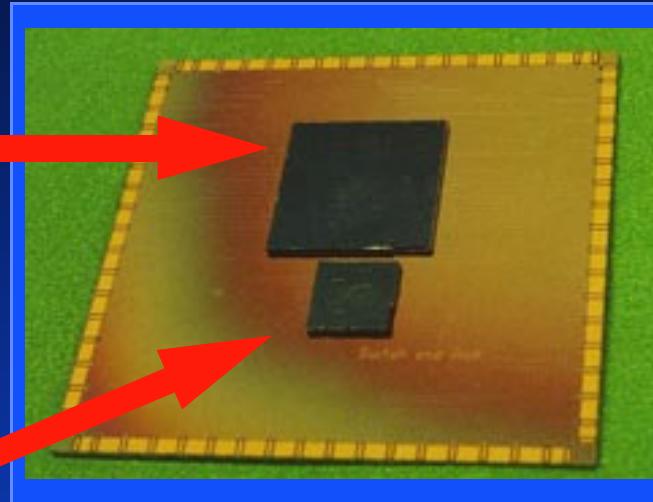
Two Chip Digital Switch Demonstration

TRW



16x16 Switch

Flip-Chip
on
BCB/Nb
Microstrip
Carrier



4 Channel SCE Amplifier

